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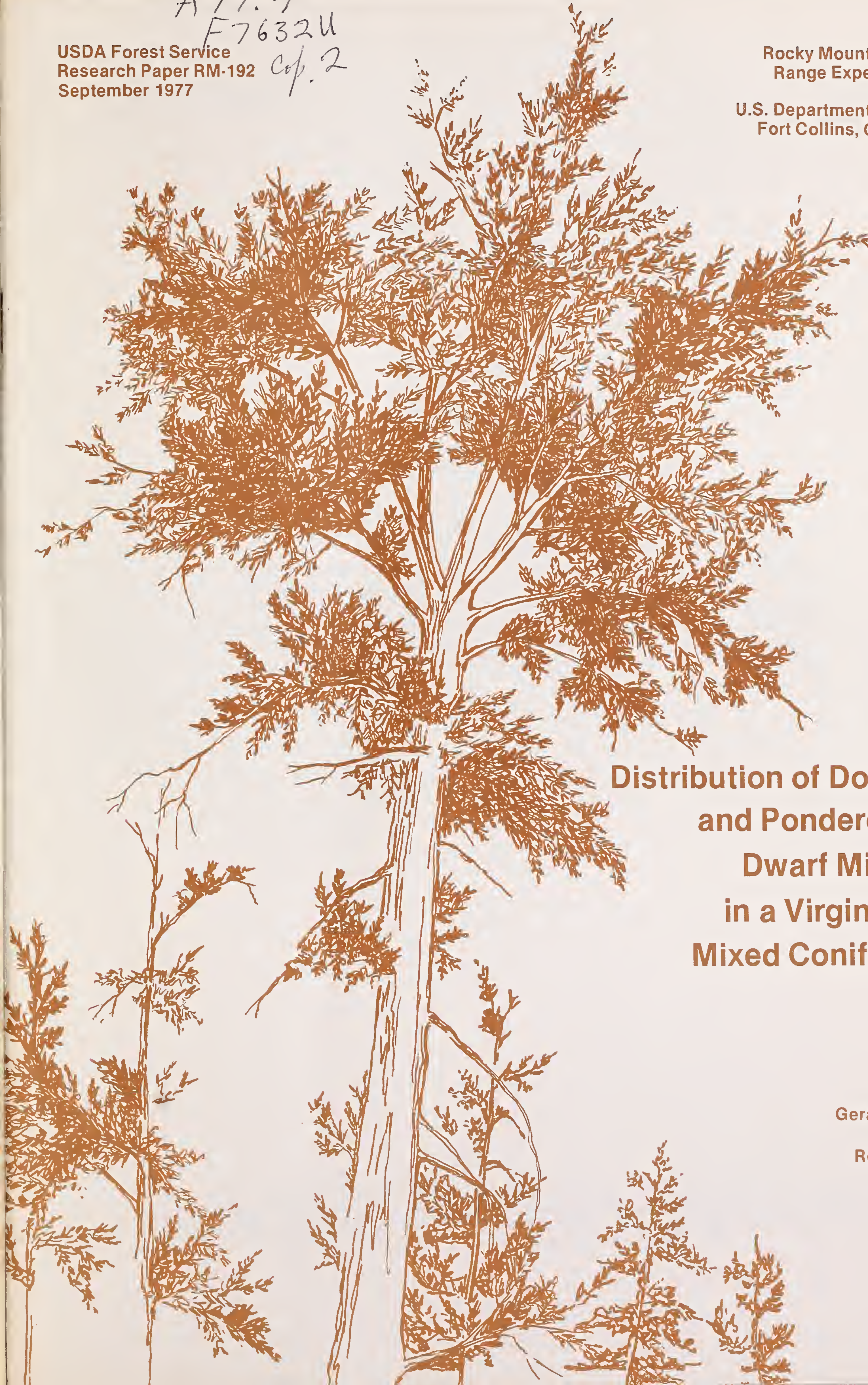

Distribution of Douglas-fir and Ponderosa Pine Dwarf Mistletoes in a Virgin Arizona Mixed Conifer Stand

Gerald J. Gottfried
and
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Abstract

Douglas-fir and ponderosa pine dwarf mistletoes are common in a 1,800-acre virgin mixed conifer stand in eastern Arizona. Dwarf mistletoes occur on approximately 21% of the Douglas-fir trees and 38% of the ponderosa pine trees. These make up 47% and 22% of the respective basal areas. The proportion and distribution of infected trees vary by topography and stand characteristics. Infestation will increase under the selection or shelterwood methods unless control measures are considered.

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Management Highlights

Dwarf mistletoes are the most important forest disease agents in the Southwest. They not only decrease growth and increase mortality, but also contribute to fire hazard because of the accelerated production of dead and down material (Alexander and Hawksworth 1975). Dwarf mistletoes are favored by any silvicultural method which opens a stand without attempting to eliminate centers of future infections.

Our objectives were to see whether there were any distribution patterns that foresters could take advantage of to reduce damage in Arizona mixed conifer stands, and to increase the basic information about dwarf mistletoe ecology. Data were collected from the 1,800 acre Willow-Thomas Creek watersheds, in the Apache-Sitgreaves National Forest, at elevations between 8,400 and 9,300 ft. The study concentrated on the two most important dwarf mistletoes in the Southwest: *Arceuthobium douglasii* which attacks Douglas-fir[2], the most common mixed conifer species, and *A. vaginatum* subsp. *cryptopodum*, which attacks ponderosa pine, the most commercially valuable species.

Approximately 21% of the Douglas-fir trees were infected with *A. douglasii*. This amounted to 47% of the Douglas-fir basal area. The percentage increased with increased diameter class. Infected Douglas-fir trees were more frequent on moderately steep slopes, on south-facing slopes, and between 9,000 and 9,100 ft. Ponderosa pine dwarf mistletoe infected 38% of the trees, which contained only 22% of the pine basal area. The percentage of infected pine decreased with increasing size class. *A. vaginatum* was found most often on steep slopes, on east and south-facing slopes, and at or below 8,700 ft. The basic distribution patterns among species, tree size class, topography, and stand variables should be characteristic of other virgin mixed conifer stands, and of partially harvested stands where timber removals were not too heavy.

The results have several management implications. They indicate that *A. douglasii* and *A. vaginatum* are common throughout the mixed conifer stand. The Douglas-fir parasite occurs on 64% of the Douglas-fir inventory points. A large percentage of the susceptible overstory trees are infected, although the infections tend to be light. However, the manager must consider occurrence as well as degree of infection when preparing silvicultural prescriptions. Vigorous trees with light infections are often not harvested, but Hawksworth (1961) indicates these trees may produce more dwarf mistletoe fruits than the heavily broomed trees which were removed. Any method that opens a dense stand without reducing or eliminating the source of dwarf mistletoe infestation (fig. 1) may result in a more rapid

Figure 1.—Dwarf mistletoe-infected trees remaining after harvest will serve as centers of new infections within the stand.

[2]Botanical names of trees are listed at the end of the paper.

spread of the parasite. We found abundant dwarf mistletoe in open stands. Increased light and improved host vigor tend to stimulate the dwarf mistletoe plants in cutover stands (Hawksworth 1961). The parasite progresses faster through an open stand, and also from an overstory to an understory.

Forest managers should be less concerned about the overstory, since most large trees can be salvaged if a short cutting cycle is initiated, and more concerned about small size classes and future regeneration. If a severe infestation becomes established in these trees, we have lost a large part of our future stand. The infected trees may survive, but growth will be retarded and they generally will not produce usable products or be esthetically pleasing (fig. 2). The problem is apparent in the Willow-Thomas Creek watersheds ponderosa pine sapling-small pole class, which is more heavily infected than any other pine size class. Ponderosa pine and Douglas-fir make up 40% of the stand, and are the most commercially valuable species in the mixed conifer forest. The loss of these desirable species would increase with time, since heavily infected trees do not produce sufficient amounts of viable tree seed (Hawksworth 1961) to adequately regenerate themselves. The dwarf mistletoe problem would perpetuate itself until fire or management eliminates the entire stand and uninfected trees become established.

Figure 2.—Advance regeneration heavily infected with dwarf mistletoe generally will not produce usable products or be esthetically pleasing.

Information relating the distribution of dwarf mistletoes to various topographic and stand characteristics can help the forest manager locate sites where *Arceuthobium* is most likely to be a serious problem. Compartment examiners could be alerted about the potential problem, for example, on a south-facing Douglas-fir site between 9,000 and 9,100 ft, prior to entering the sites. If the examination confirms the presence of unacceptable levels of dwarf mistletoe, an appropriate silvicultural prescription could be prepared.

The large number of tree species present in southwestern mixed conifer stands, and the fact that dwarf mistletoes are host specific, provide an opportunity to control the spread of dwarf mistletoe without opening the stand to excessive windfall or creating unacceptably large clearings. Jones (1974) has developed model silvicultural prescriptions for several southwestern mixed conifer stand conditions which consider both dwarf mistletoe and windfall. He generally calls for the removal of the diseased overstory in a series of entries into the stand covering not more than 20 yr. The windfall risk would determine the amount to be removed in each cut. Understories should be inspected and sanitized as necessary; at least three inspections may be required. Jones indicates that severely infected understories should be cleared. Such stands could be underplanted. If both overstory and understory are heavily infected, and there are not enough nonsusceptible trees to maintain windfirmness, the stand or patch should be clearcut and planted. Clearcut size would be limited by other multiple use considerations. The creation of small patch-cuts could be beneficial for water yield improvement and for natural regeneration, provided the border trees are not infected. Prescribed fire could be used to create such openings and to eliminate diseased regeneration under an existing overstory. Alexander and Hawksworth (1975) discuss other possibilities of using fire to control dwarf mistletoes.

Artificial regeneration provides the manager with a tool to manipulate stand structure and productivity, and still reduce the level of dwarf mistletoe infestation. If a diseased overstory cannot be removed over a short interval, the site could be underplanted with seedlings of nonsusceptible species. For example, spruce could be

planted under a Douglas-fir canopy or Douglas-fir could be planted under a ponderosa pine canopy. If sanitation leaves the stand understocked with Douglas-fir advance regeneration, the species could be underplanted in areas dominated by other overstory species, such as white fir. Species and site must be carefully matched, however. Every precaution must also be taken to protect the regeneration during subsequent harvesting operations. Although both planting and special logging restrictions are expensive, so is a deformed, unproductive forest.

Mixed Conifer Study Area

The study was conducted on the Willow-Thomas Creek area of eastern Arizona, in the Apache-Sitgreaves National Forest, about 20 mi south of Alpine. The four experimental watersheds encompass 1,800 acres of virgin mixed conifer forest. The watersheds have not had a major forest fire in approximately 90 to 100 yr[3]. Stand characteristics of tree species are presented in table 1.

Four species of dwarf mistletoe are found on the Willow-Thomas Creek area. The most important are *Arceuthobium douglasii* Engelm., which attacks Douglas-fir, and *A. vaginatum* subsp. *cryptopodum* (Engelm.) Hawks. and Wiens, which attacks ponderosa pine. Both species are near their upper altitudinal limits on the study area.[4] Two other minor species are also present: *A. microcarpum* (Engelm.) Hawks. and Wiens, which infects the two spruce species, and *A. apachecum* Hawks. and Wiens, which infects southwestern white pine.

Forty-seven percent of the study area faces east and southeast. Twenty percent slopes are most frequent, occurring on 19% of the area, but slopes vary from almost level to over 60%. Elevations range from 8,400 to 9,300 ft, with 49% of the area between 9,000 and 9,100 ft. Soils are a stony, silty clay loam derived from basalt parent material. Average annual precipitation is about 29 in.

[3]*Dieterich, J. H. 1976. Personal conversation. USDA For. Serv. Rocky Mountain For. and Range Exp. Stn., Tempe, Ariz.*

[4]*Hawksworth, F. G. 1976. Personal correspondence. USDA For. Serv., Rocky Mountain For. and Range Exp. Stn., Fort Collins, Colo.*

Methods

Little work has been done with dwarf mistletoes in the southwestern mixed conifer forests. Efforts have mainly been directed towards problems in the ponderosa pine type, although Douglas-fir dwarf mistletoe was also included in studies by Hawksworth and Lusher (1956), Hawksworth (1959), and by Andrews and Daniels (1960). The last two studies did not consider Douglas-fir or ponderosa pine on plots where they were of secondary importance, however. In mixed conifer stands, this procedure would eliminate a large percentage of the trees from any sample. The intimate intermixing of forest types characteristic of the Arizona stands would also make such a division artificial.

Dwarf mistletoe data were collected during the 1969 timber inventory on the Thomas Creek watersheds and the 1970 reinventory on Willow Creek. Data were checked and updated in 1974 on three of the areas. The East Fork of Willow Creek was checked prior to harvesting in 1972. Timber inventory information was collected at permanent sampling points established on each watershed. A total of 556 sample points have been es-

Table 1.—Characteristics of the 1,800-acre Willow-Thomas Creek mixed conifer stand (per-acre conditions, based on a 25 BAF cruise)

Species	Trees		Basal area		Gross volume	
	No.	*% of total*	*Ft²*	*% of total*	*Bd ft*	*% of total*
Douglas-fir	157.9	31.3	59.3	31.8	6,538	30.3
Ponderosa pine	46.3	9.2	24.8	13.3	4,255	19.6
Engelmann spruce	74.1	14.7	26.2	14.1	3,086	14.2
Blue spruce	12.3	2.4	3.2	1.7	353	1.6
White fir	66.3	13.1	26.6	14.3	3,711	17.1
Corkbark fir	18.9	3.7	6.3	3.4	605	2.8
White pine	35.4	7.0	10.5	5.6	1,009	4.6
Aspen	78.8	15.6	28.7	15.4	2,124	9.8
Other	15.4	3.0	0.8	0.4	0	0
Total	505.4	100.0	186.4	100.0	21,681	100.0

tablished. Point sampling techniques were used to select trees for measurement with a 25 BAF angle gage. We sampled 1,317 Douglas-fir trees occurring on 423 points, and 551 ponderosa pine trees occurring on 233 points. All points with at least one Douglas-fir or ponderosa pine tree were included. The presence of dwarf mistletoe was determined by evidence of the characteristic witches'-brooms — especially on Douglas-fir — or of the parasite. Degree of infection was determined by Hawksworth's (1961) 6-class mistletoe rating system (fig. 3) for Douglas-fir and ponderosa pine trees on 374 points surveyed in 1974. No attempt was made to relate recent mortality or changes in periodic growth to *Arceuthobium.*

Distributions and proportions of infected trees are presented in terms of trees per acre and basal area (ft^2) per acre. The combination of the two parameters gives the density of the stand and also an indication of the dominant size classes. For example, a large number of trees with a small basal area per acre would indicate a large number of small trees.

Trees were divided into five size classes according to their diameter (in inches) at breast height:

Sapling-small poles	0.1-6.9
Large poles	7.0-10.9
Small sawtimber	11.0-16.9
Medium sawtimber	17.0-22.9
Large sawtimber	23.0 and above

Each inventory point was classified by aspect, percent slope, elevation and slope position (upper one-sixth, intermediate two-thirds, or lower one-sixth). Aspects were grouped into the four cardinal directions by combining: north and northeast; east and southeast; south and southwest; and west and northwest. Percent slopes were grouped into three classes: gentle (below 7%), moderate (8% to 32%) and steep (above 33%). Elevations (in feet) were divided into four groups: 8,700 or lower, 8,800-8,900, 9,000-9,100 and 9,200-9,300.

Dwarf mistletoe percentages were calculated separately for each topographic site. These values are shown together with data indicating the distribution of the total study area basal area or trees per acre for the particular host (figs. 4-7). The percentages can range from 1% to 100% for each site, while the total stand distributions must equal 100%. A heavily infested site that contains only a small percentage of Douglas-fir would be of less concern to a manager than a moderate infestation on a more common site.

Points with Douglas-fir or ponderosa pine were classified by three stand characteristics: total basal area of all species on the point, percent of this basal area contributed by the host species, and number of host size classes on the point. Point basal area values were calculated by multiplying the number of trees by 25, and were accordingly grouped into three classes: 25-125 ft^2, 150-250 ft^2, and 275 ft^2 or greater. Percent basal area was classified as 1-25%, 26-50%, 51-75%, or 76-100%.

It is obvious there are numerous interactions among the different topographic, stand characteristic, tree size, and dwarf mistletoe infesta-

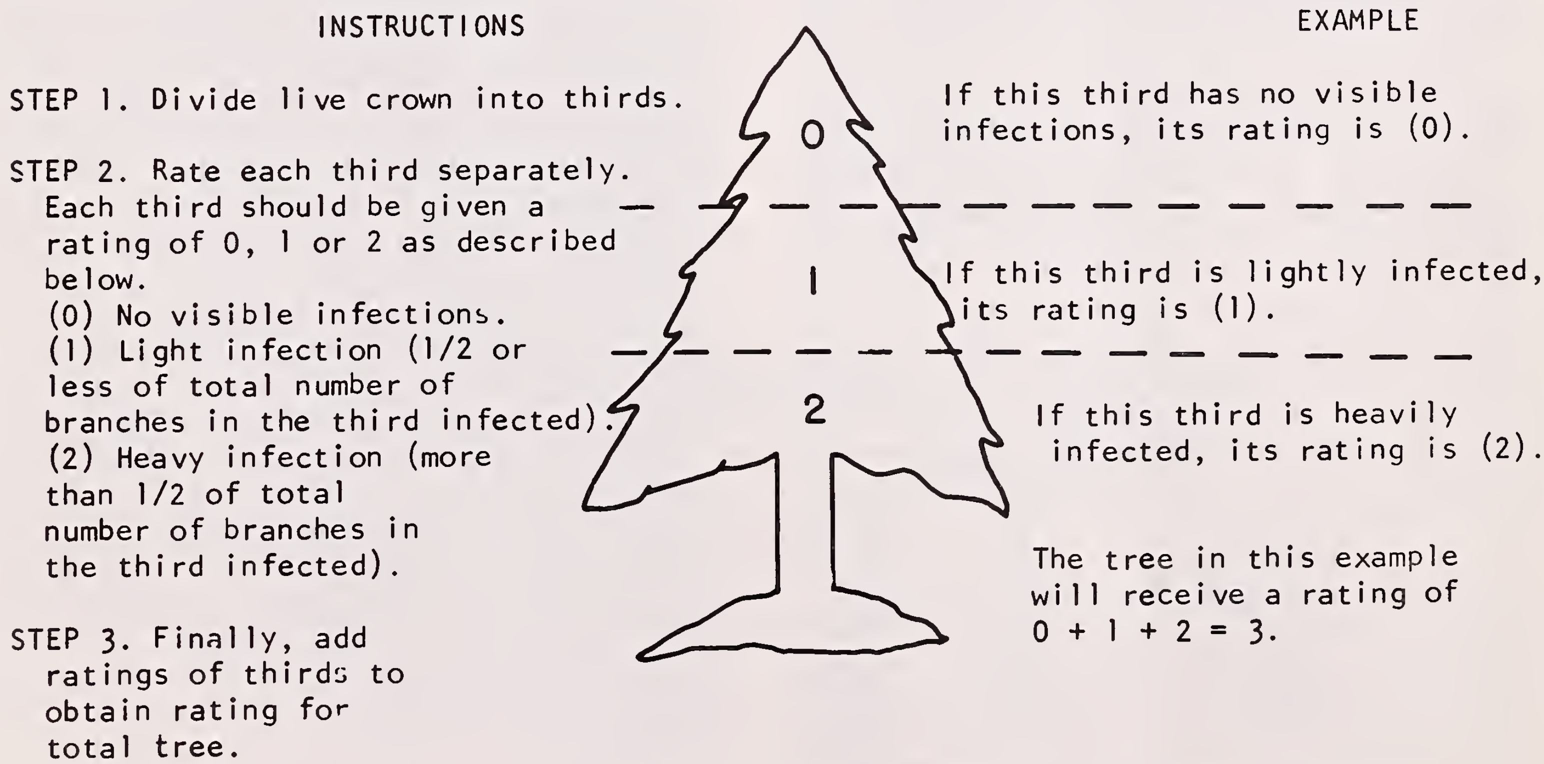

Figure 3.—Instructions for and example of the use of the 6-class mistletoe rating system (Hawksworth 1961).

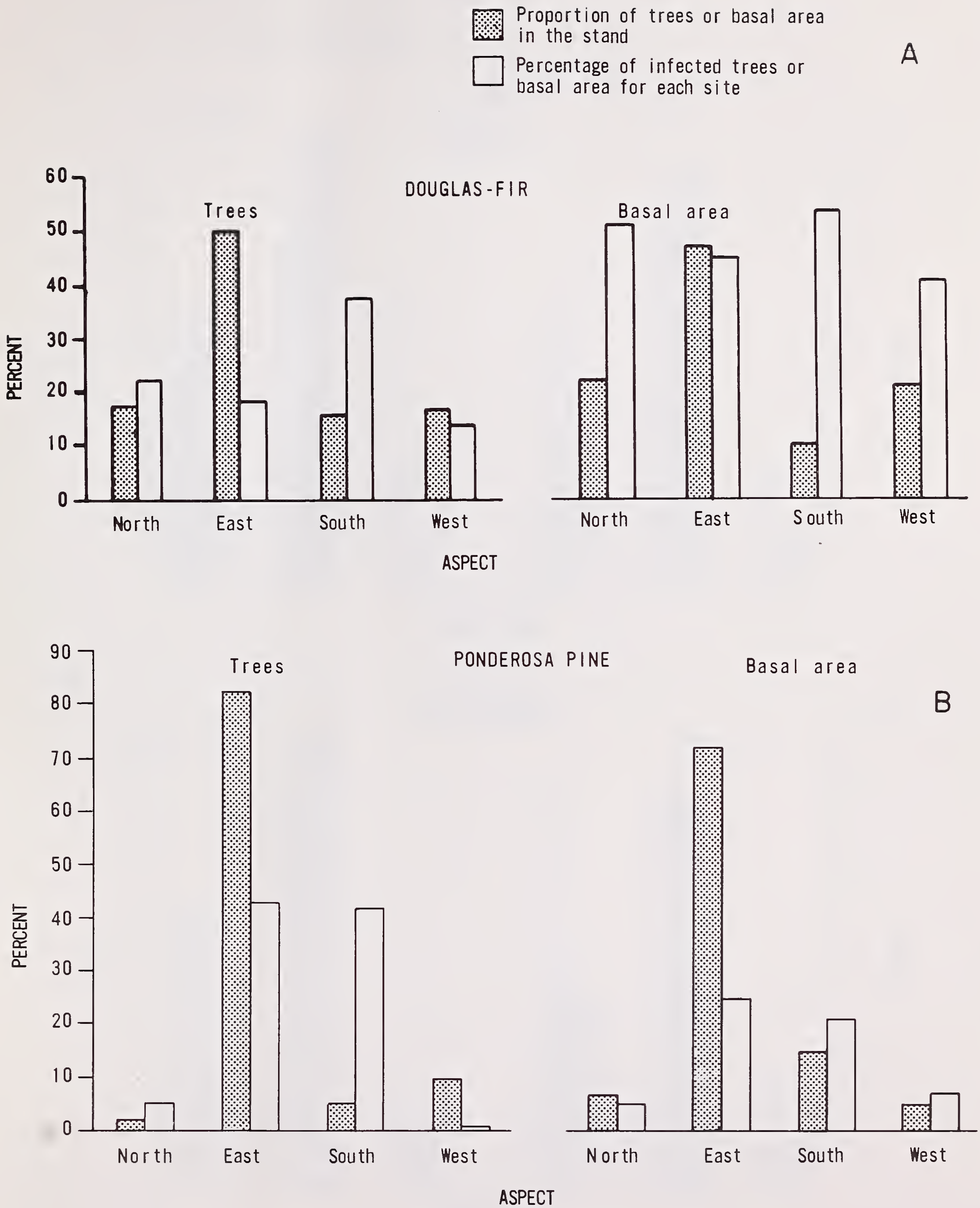

Figure 4.—The percentage of infected Douglas-fir trees was highest on south aspects (A), while the percentage of infected ponderosa pine trees was highest on east and south aspects (B).

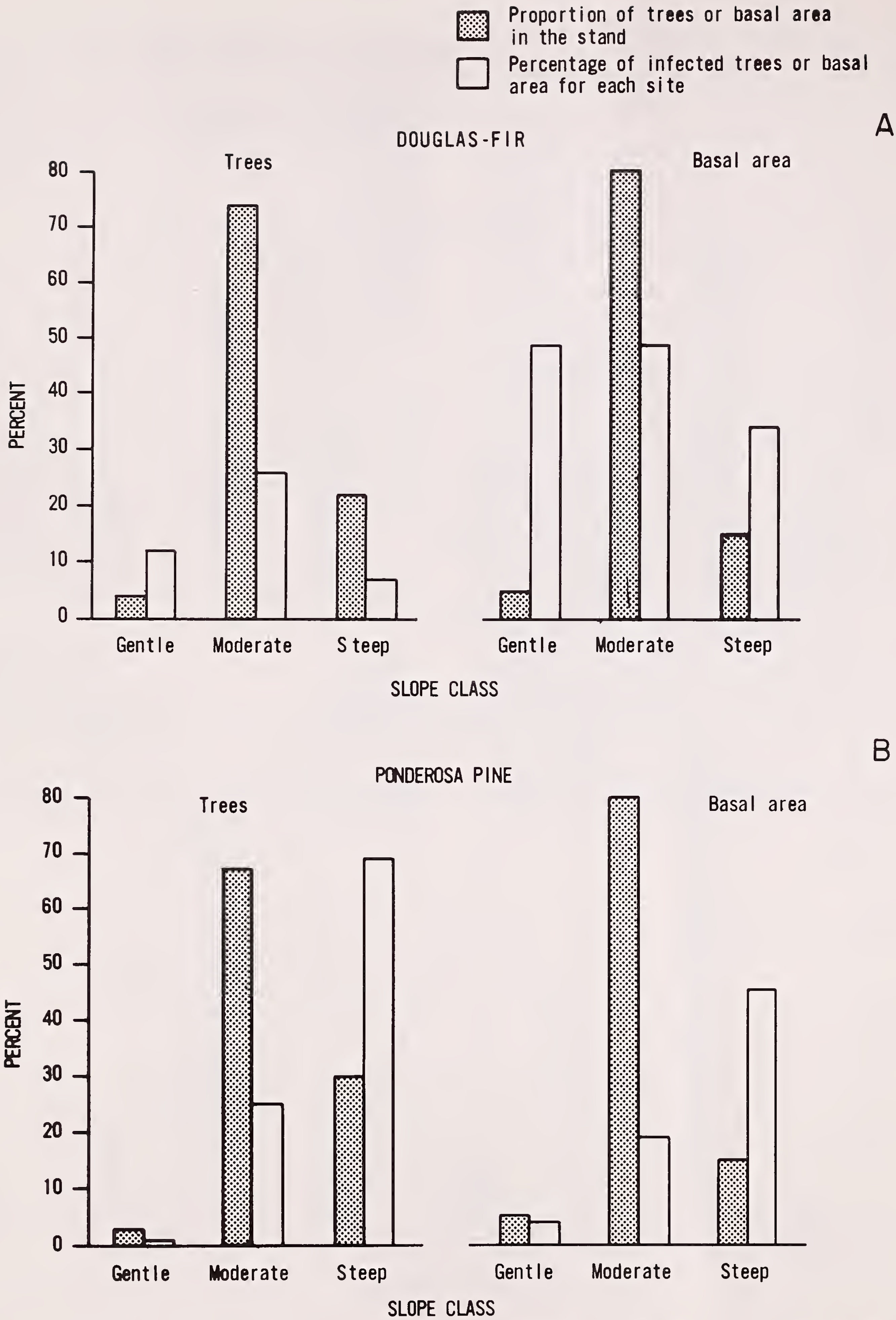

Figure 5.—The percentage of infected Douglas-fir trees was highest on moderately steep slopes (8-32%) (A), while the percentage of infected ponderosa pine trees increased with increased steepness (B). The ponderosa pine basal area data indicated significant differences.

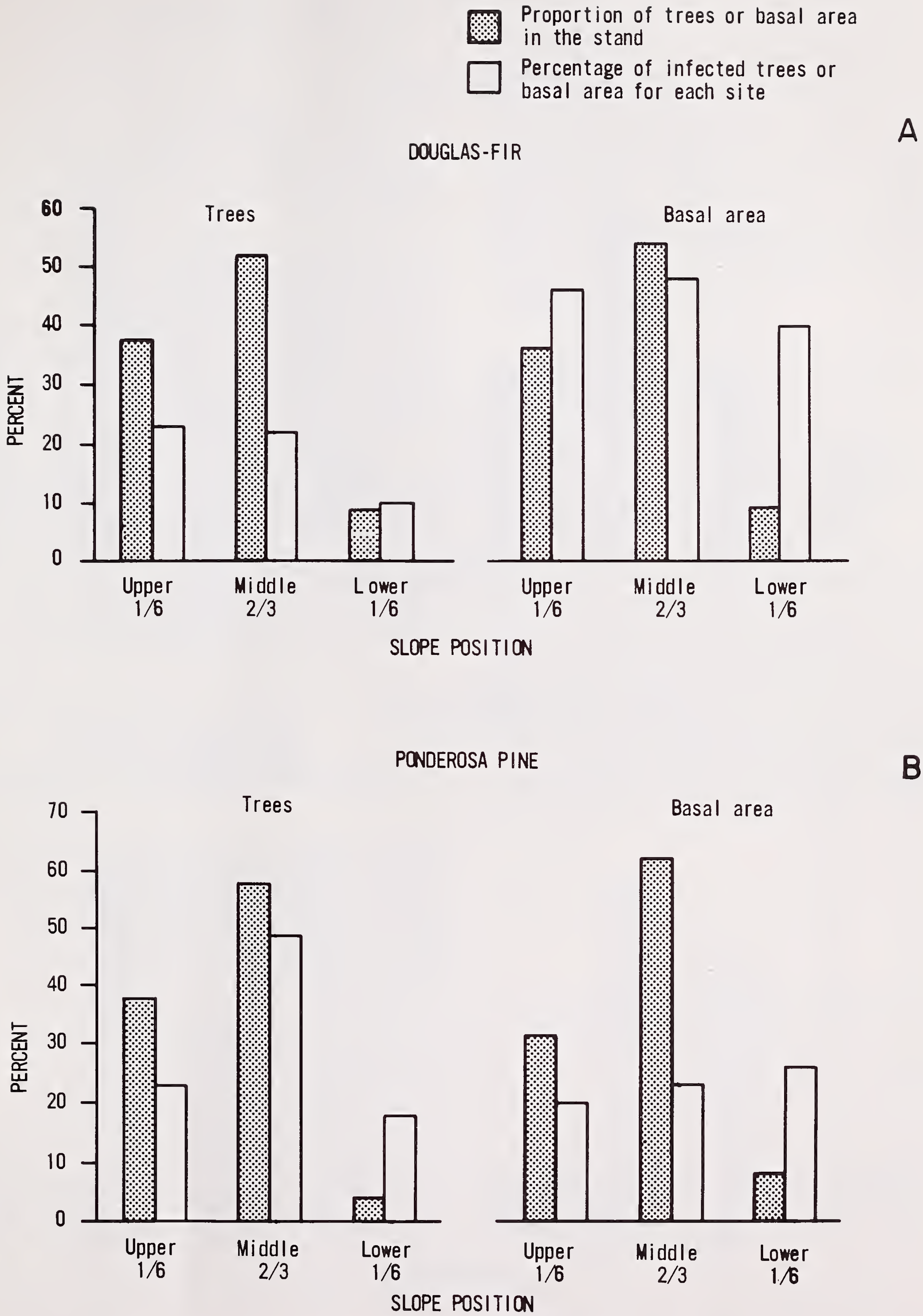

Figure 6.—Upper and middle slope positions contained a higher percentage of infected Douglas-fir trees than did lower slope positions (A), while the percentage of infected ponderosa pine trees was highest on middle slope positions (B).

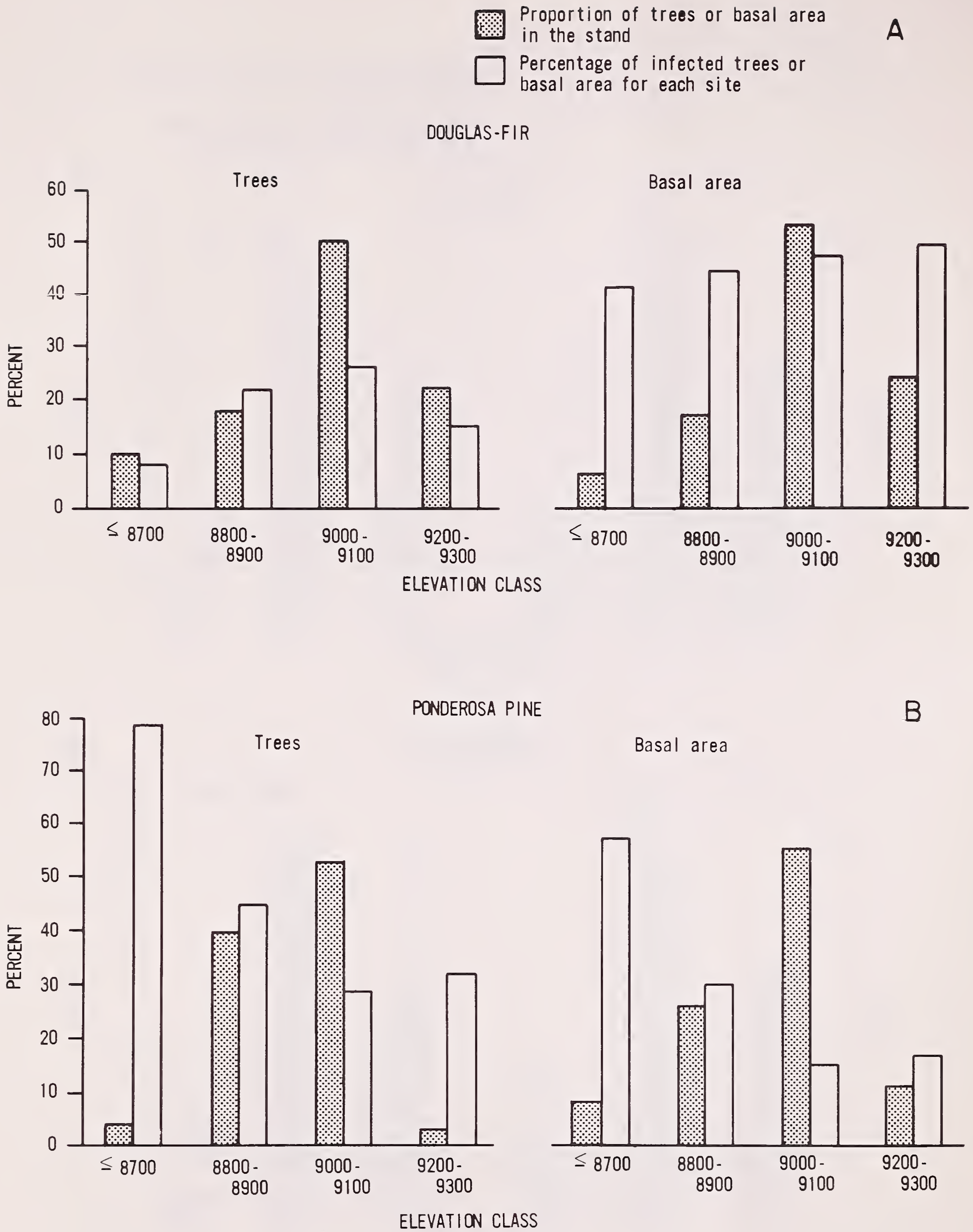

Figure 7.—The percentage of infected Douglas-fir trees was smallest in the lowest elevation class (A), but this class contained the highest percentage of infected ponderosa pine trees and basal area in infected trees (B).

tions. Our data base was not large enough to support a thorough interaction analysis, however. We have presented tables showing selected cells of 2-way topographic and stand characteristic classes for both species. There are six topographic and three stand classes. The results of the cell characteristic comparisons are presented to show conditions with highest and lowest occurrence of the disease, and the occurrence of the disease for the most common conditions (see tables 4, 5, and 7).

The number of points sampled is used as the denominator in calculating trees per acre and basal area per acre. Any values referring to the entire stand used all 556 points. Values derived for a particular topographic site only used points present on that site. The relationships between dwarf mistletoe and the stand characteristics were developed for just the points containing Douglas-fir or ponderosa pine with the specified feature.

Regression analyses were used to evaluate the relationships between proportion of infection and tree size class. Chi-square tests were used to compare differences within the topographic and stand characteristic classes. Most relationships discussed in the text are significant at the 5% level, although values above the 1% level were not uncommon.

Results and Discussion

Distribution of Dwarf Mistletoes by Species and Size Class

Douglas-fir. Douglas-fir is the most common species on the study area and in the southwestern mixed conifer forests. The distribution of Douglas-fir — or any other species — within a stand is partially related to the historical development of the stand. The same is true for obligatory parasites such as *Arceuthobium* spp. We found an average of 21% of the Douglar-fir trees were infected by *A. douglasii.* Forty-seven percent of the Douglas-fir basal area and 60% of the Douglar-fir gross board foot volume were in infected trees. At least one infected Douglar-fir tree was found on 64% of the points stocked with that species. Although our results are not directly comparable because of differences in sampling techniques and criteria, Hawksworth (1959) found infections on only 33% of the Mescalero-Apache Reservation Douglas-fir plots, and Andrews and Daniels (1960) found infections on 50% of the Arizona-New Mexico plots.

The proportion of trees with *A. douglasii* increased linearly as the host size class increased (table 2). The relationship between infection and size class is similar to that reported by Hawksworth (1961) for pure ponderosa pine stands. It is assumed that the same general mechanisms for the spread and the intensification of the infestation operate in the mixed conifers as in pure ponderosa pine stands. Hawksworth (1961) indicates that smaller trees present a smaller target than do larger trees, and are less likely to be hit by dwarf mistletoe seeds. It is possible that more small trees are infected than we recorded, since dwarf mistletoe infections can remain latent. The proportion of Douglas-fir basal area in infected trees showed the same relationship to size class as did proportion of trees.

Ponderosa pine. An average of 38% of the ponderosa pine trees had dwarf mistletoe. Twenty-two percent of the basal area and 19% of the ponderosa pine gross board foot volume on the Willow-Thomas Creek watersheds were in infected trees. Twenty-nine percent of sample points containing ponderosa pine had at least one ponderosa pine with *A. vaginatum.*

The proportion of ponderosa pine trees with dwarf mistletoe decreased linearly with increased size class (table 2), contrary to Hawksworth's (1961) observations for pure pine stands, as did basal area. The percentage of ponderosa pine basal area (22%) in infected trees was also much lower than Douglas-fir (47%). Both facts are indicative of the screening provided by the intermixed species on most sites. Most large ponderosa pine occur singly or paired on sample points dominated by other species. Their relative isola-

Table 2.—Distribution of Douglas-fir and ponderosa pine dwarf mistletoes in terms of trees per acre and basal area per acre, by size class, for the four Willow-Thomas Creek watersheds

Size class	Trees	Total trees	Trees with dwarf mistletoe	Basal area	Total basal area	Basal area with dwarf mistletoe
	No.	%	%	Ft^2	%	%
			Douglas-fir			
Sapling-small poles	120.5	76.3	15.8	8.3	14.0	15.2
Large poles	15.6	9.9	28.6	6.5	11.0	24.8
Small sawtimber	12.0	7.6	44.2	12.4	20.9	45.6
Medium sawtimber	5.1	3.2	51.6	11.0	18.6	52.0
Large sawtimber	4.7	3.0	61.5	21.1	35.5	63.5
All classes	157.9	100.0	21.3	59.3	100.0	46.6
			Ponderosa pine			
Sapling-small poles	33.9	73.2	42.5	2.2	8.9	42.0
Large poles	3.1	6.7	29.0	1.4	5.6	26.7
Small sawtimber	3.5	7.6	31.4	3.7	14.9	26.8
Medium sawtimber	3.2	6.9	20.2	7.1	28.6	20.2
Large sawtimber	2.6	5.6	17.3	10.4	42.0	17.3
All classes	46.3	100.0	37.8	24.8	100.0	22.3

tion reduces the probability of getting or transmitting the infection. Trees in the smaller size classes appear to be more clustered. Larson et al. (1970) found no significant size related differences in the distribution of dwarf mistletoe in cutover ponderosa pine.

Associated species. The two other species of dwarf mistletoe — *Arceuthobium microcarpum* and *A. apachecum* — had relatively little effect on the spruce and white pine components of the stand. Approximately 2% of the Engelmann spruce trees (3% of the basal area) were infected. *A. microcarpum* was found on 5.4% of the 221 points which contained Engelmann spruce. Acciavatti and Weiss (1974) found a comparable 6.8% of the Engelmann spruce observation points in the mixed conifer forests of the Fort Apache Indian Reservation contained dwarf mistletoe. The Reservation is adjacent to the Apache-Sitgreaves National Forest. Blue spruce was more heavily infected (5%) than Engelmann spruce on the Willow-Thomas Creek area. This represented 22% of the basal area. Slightly over 18% of the 38 blue spruce inventory points contained infected trees. *A. apachecum* was observed on less than 1% of the white pine trees. These trees contained 2% of the basal area. Only 3% of the 152 points with white pine contained infected trees.

We did not observe any dwarf mistletoe on corkbark fir, although that species can serve as a secondary host for *A. douglasii* (Hawksworth and Wiens 1972). Douglas-fir and corkbark fir often occur near each other.

Witches'-brooms were reported on several large white firs, but we believe that they were probably the result of rusts, since the nearest known location of white fir dwarf mistletoe (*A. abietinum* Engelm. ex Munz f. sp. *concoloris*) is about 110 miles to the south in the Chiricahua Mountains (Mathiasen 1977). It is also possible that the white fir was parasitized by *A. douglasii*, but we did not make a determination. Less than 1% of the white fir trees in the stand contained witches'-brooms. These trees made up 3% of the basal area, and were found on 7% of the 227 white fir sample points. The suspected infections were light, and would have been in dwarf mistletoe rating classes 1 or 2.

Severity of Dwarf Mistletoe Infections

Infected Douglas-fir and ponderosa pine trees on the two Thomas Creek watersheds and the Willow Creek West Fork watershed were rated by Hawksworth's (1961) 6-class mistletoe rating system (table 3). Mistletoe rating classes 1 through 3 were grouped together, as were 4 through 6. Hawksworth (1961) found no significant difference in radial growth between uninfected trees and class 3 trees in a merchantable ponderosa

Table 3.—Distribution of Douglas-fir and ponderosa pine dwarf mistletoes by size class and mistletoe rating, in terms of trees and basal area per acre for three of the Willow- Thomas Creek watersheds

Size class	Trees per acre	Trees in dwarf mistletoe rating class: 1-3	Trees in dwarf mistletoe rating class: 4-6	Basal area per acre	Basal area in dwarf mistletoe rating class 1-3	Basal area in dwarf mistletoe rating class 4-6
	No.	%	%	Ft^2	%	%
Douglas-fir						
Sapling-small pole	151.5	10.6	8.0	10.2	13.2	5.3
Large poles	16.6	22.3	8.0	7.0	23.0	7.8
Small sawtimber	10.6	35.9	16.3	10.8	37.7	16.6
Medium sawtimber	4.5	37.5	17.2	9.6	37.8	16.6
Large sawtimber	4.1	42.3	21.6	18.1	43.1	22.2
All classes	187.3	14.4	9.0	55.7	33.2	15.2
Ponderosa Pine						
Sapling-small pole	46.5	32.2	13.9	2.8	43.1	7.1
Large poles	3.2	40.3	—	1.4	37.9	—
Small sawtimber	4.3	36.5	—	4.4	33.5	—
Medium sawtimber	3.8	24.9	—	8.6	25.0	—
Large sawtimber	2.7	21.3	0.7	11.0	20.8	0.6
All classes	60.5	32.0	10.7	28.2	27.2	1.0

pine stand. Growth reductions proportional to the mistletoe rating were determined for trees in classes 4 through 6.

Although dwarf mistletoe is common throughout the stand, most infections are light. Fourteen percent of all the Douglas-fir trees containing 33% of the basal area on the three watersheds have a dwarf mistletoe rating of 1 to 3. This amounts to about 62% of the infected trees. This is equivalent to 68% of the basal area in infected trees. There seems to be an approximate 2:1 ratio between light and heavy infections within the Douglas-fir size classes. Many recent Douglas-fir snags contained evidence of class 5 or 6 infections.

Thirty-two percent of all the ponderosa pine trees (containing 28% of the ponderosa pine basal area) have light dwarf mistletoe infections. About 75% of all the infected trees have only light infections; they contain 96% of the pine basal area in infected trees. Heavy infections are primarily in the sapling-small pole class. Approximately 30% of the diseased sapling-small pole trees, which make up 14% of the basal area, are heavily infected.

Distribution of Dwarf Mistletoes by Topographic Parameters

The distribution of dwarf mistletoes varied significantly within the various topographic and combined topographic classes. A knowledge of the differences should be helpful in timber management planning and in increasing the information about dwarf mistletoe ecology. We did not attempt to determine reasons for the differences. Many interacting factors (such as solar radiation and temperature) normally affect the microclimate, and consequently, the tree and parasite physiology.

The following discussion generally deals with the significant differences. Distributions and percentages for other sites are indicated in figures 4-7 and in tables 4 and 5.

Aspect. The percentage of Douglas-fir trees infected with dwarf mistletoe was much higher on south-facing slopes (38%) than on any other slope direction (average of 18%). Fifty-four percent of the basal area on south-facing slopes was in infected trees (fig. 4). Douglas-fir constitutes 49% of the trees on these slopes compared to 35% on east-facing slopes, where — because of the preponderance of east-facing slopes — most of the Douglas-fir are found. South-facing slopes contain fewer nonsusceptible trees to hinder the dispersion of dwarf mistletoe seeds. Hawksworth (1959) found *A. douglasii* most often on north slopes within the Mescalero-Apache Reservation, but the most common elevations there were 7,800-7,900 ft — 1,200 ft below the mode for Willow-Thomas Creek. The comparison implies that the distribution of both host and parasite is influenced by an aspect x elevation interaction.

Table 4.—Percentages of Douglas-fir infected with dwarf mistletoe, by selected cells from six topographic interaction tables (per-acre basis)

Topographic interaction	Greatest occurrence: Position(s)	Greatest occurrence: Trees	Greatest occurrence: Basal area	Most common site: Position(s)	Most common site: Trees	Most common site: Basal area	Least occurrence: Position(s)	Least occurrence: Trees	Least occurrence: Basal area
		...... %			...... %			...... %	
Aspect x elevation	South, 9,000-9,100	47	50	East, 9,000-9,100	24	49	East, ≤ 8,700	2	21
	West, ≤8,700	14	65						
Aspect x slope position	West, lower	46	71	East, middle	19	45	East, lower	7	32
Aspect x slope	South, moderate	44	56	East, moderate	23	50	East, steep	2	20
	North, gentle	36	60						
Elevation x slope position	9,200-9,300 lower	58	33	9,000-9,100 middle	25	48	≤ 8,700 lower	5	37
Elevation x slope	≤ 8,700 moderate	33	43	9,000-9,100 moderate	30	48	9,000-9,100 steep	5	33
	9,000-9,100 gentle	14	56						
Slope x slope position	Moderate, middle	30	52	Moderate, middle	30	52	Gentle, lower	0	0

Table 5.—Percentages of ponderosa pine infected with dwarf mistletoe, by selected cells from six topographic interaction tables (per-acre basis)

Topographic interaction	Greatest occurrence Position(s)	Trees	Basal area	Most common site Position(s)	Trees	Basal area	Least occurrence Position(s)	Trees	Basal area
		....	%.........		....	%.........		......	%......
Aspect x elevation	North, ≤ 8,700	100	100	East, 9,000-9,100	29	14	West 8,800-8,900	0	0
	East, ≤ 8,700	79	55				North, 8,800-8,900	0	0
Aspect x slope position	East, Middle	54	25	East, Middle	54	25	West, Middle	0	0
	East, Lower	20	30						
Aspect x slope	North, steep	100	100	East, moderate	30	22	West, steep	0	0
	East, steep	69	43				North, gentle	0	0
Elevation x slope position	≤ 8,700 middle	80	59	9,000-9,100 middle	46	14	9,200-9,300 middle	0	0
Elevation x slope	≤ 8,700 moderate	90	72	9,000-9,100 moderate	24	13	8,800-8,900 gentle	0	0
Slope x slope position	Steep, lower	80	29	Moderate, middle	30	17	Gentle, upper	0	0
	Steep, middle	69	47						

Smith (1972), working at the northern limit of *A. douglasii* in British Columbia, found the highest parasite intensity on a southwest-facing slope, which contained the largest percentage of Douglas-fir trees.

The proportion of trees with ponderosa pine dwarf mistletoe was highest on east- and south-facing slopes (fig. 4). Forty-two percent of the pine trees on these sites were infected. Twenty-three percent of the basal area was in these trees. On west-facing slopes, less than 1% of the trees were infected.

Slope Class. A higher proportion of trees on moderate slopes contained *A. douglasii* (26%) than on gentle and steep slopes, where they averaged 10% (fig. 5). Hawksworth (1959) reported slightly more Douglas-fir infections on steep slopes than on moderate slopes. Hawksworth based his relationship on frequency of *A. douglasii* in plots in which Douglas-fir was the principal component.

The percentage of ponderosa pines infected with *A. vaginatum* showed a strong positive gradient with steepness (fig. 5), with a range of 1% to 69%. The basal area data also showed a gradient from gentle (4%) to steep slopes (45%). Hawksworth (1959) found a slight decrease in infection with increased slope on the Mescalero-Apache Reservation.

Slope Position. Douglas-fir dwarf mistletoe infected an average of 23% of the trees on upper and middle slopes and 10% on lower slopes (fig. 6). Douglas-fir is a smaller proportion of the stand on lower slope positions (23%) than on the other positions (average 32%). Lower slopes and bottoms often contain dense stands of spruce and corkbark fir, which can reduce the spread of *A. douglasii* by screening. Hawksworth (1959) found no significant slope-related differences for Douglas-fir on the Mescalero-Apache Reservation.

Previous work in the southwestern ponderosa pine type has indicated greater occurrence of *A. vaginatum* on ridges (Hawksworth 1961). However, the parasite occurred on 49% of the pine trees on middle slope positions (fig. 6) on the study area, compared to an average 21% on the other two slope positions.

Elevation. Little work has been reported on the distribution of Douglas-fir and ponderosa pine dwarf mistletoes above 8,600 ft; most of the Willow-Thomas Creek watersheds are above this

elevation. We found that only 8% of the Douglas-fir trees in the lowest elevation class were infected, less than in the other three classes where an average of 21% of the trees contained the parasite (fig. 7). Over 26% of the trees in the 9,000-9,100 ft elevation class contained *A. douglasii*. This was higher than the proportion for the 9,200-9,300 ft class where 15% were infected.

Occurrence of *A. vaginatum* tended to decrease with increased elevation (fig. 7). Although only 4% of all ponderosa pine trees and 8% of the species basal area on the watersheds were at or below 8,700 ft, 79% of these trees (57% of the basal area) were infected with the parasite. An average of 36% of the trees in the next three higher classes contained dwarf mistletoe. Most pine was found at 8,800-9,100 ft. Thirty-seven percent of the trees, with 22% of the basal area, contained dwarf mistletoe at these elevations.

Combined Topographic Class. We performed a limited interaction analysis on combined data from two topographic parameters. Slope position, aspect, slope percent class, and elevation can be combined into 6 major categories. The largest percentage of Douglas-fir trees infected with dwarf mistletoe (58%) occurred on lower slopes and bottoms at 9,200-9,300 ft (table 4). Gentle lower slopes contained no infected trees. Ninety percent of the ponderosa pine trees on moderate slopes at 8,700 ft elevation or less were infected (table 5). Mid-slopes, between 9,000-9,100 ft, were the most common sites; 25% of the Douglas-fir and 46% of the ponderosa pine trees on these locations were infected. The trees contained 40 and 14% of the respective basal areas.

Distribution of Dwarf Mistletoes by Stand Parameters

Stand characteristics — the number of size classes, total plot density, and relative host density — were evaluated to indicate conditions where dwarf mistletoes could be a problem. Timber harvesting would change all three characteristics, and would alter the nature of the infestation.

Number of Size Classes. The number of Douglas-fir or ponderosa pine size classes present on a site was compared to the occurrence of dwarf mistletoe. We assumed that number of size classes could serve as an "indicator" of the number of stand canopy levels, although trees from two adjacent size classes in a multi-storied stand could be in the same level.

On sites with three or four size classes, an average of 31% of the Douglas-fir trees were infected, compared to 17% for sites with one or two size classes (table 6.) Although no differences were found among the first three ponderosa pine groups, there were more infections in the multi-storied than in the single-storied sites (table 6).

Table 6.—Distribution of Douglas-fir and ponderosa pine dwarf mistletoes as affected by various stand characteristics (per acre basis)

		Douglas-fir					Ponderosa pine			
		Trees		Basal area			Trees		Basal area	
Stand characteristic	No. points	Aver. on point	In-fected	On point	In-fected	No. points	Aver. on point	In-fected	Aver. on point	In-fected
		No.	%	Ft²	%		No.	%	Ft²	%
Number of host size classes										
1	176	86.6	20.1	39.6	48.4	135	34.3	36.9	33.0	23.6
2	143	272.3	15.0	80.4	47.4	64	115.8	54.1	79.3	23.6
3	74	269.1	30.0	127.7	49.2	28	226.5	44.7	116.1	22.3
4	26	437.0	32.6	163.4	39.4	6	1228.4	16.1	166.7	10.0
5	4	588.1	3.6	187.5	26.7					
Point basal area class										
25-125 ft²	87	123.6	23.3	43.7	41.4	73	84.9	72.8	47.6	38.1
150-250 ft²	248	179.7	22.7	72.4	48.0	119	78.4	19.0	62.8	16.0
≥ 275 ft²	88	369.1	18.6	127.0	46.1	41	249.3	33.6	68.9	19.5
Percent of point basal area in host species										
≤ 25%	149	103.7	13.4	35.6	42.0	119	29.1	12.1	30.9	17.7
26-50%	173	207.0	31.9	78.9	52.6	63	87.6	31.1	71.0	20.7
51-75%	82	367.0	15.6	133.2	45.5	25	131.7	20.5	101.0	15.8
76-100%	19	339.7	7.5	160.5	32.0	26	518.4	51.3	119.2	35.5

Hawksworth (1961) found that dwarf mistletoe spread more rapidly from overstories to understories than through a single-storied stand. The data show a sharp drop in the proportion of trees infected on plots with the largest number of size classes. Although we cannot make any definite statements on this observation since our sample size was relatively small, it could indicate temporary screening of smaller size classes by several stories of larger trees. Douglas-fir or ponderosa pine trees can also serve as a screen between infected and uninfected trees, but their effectiveness will be temporary.

Total Point Basal Area Class. Dwarf mistletoe occurrence information was grouped according to the total basal area of all trees on an inventory point. The Douglas-fir evaluations did not reveal any effect due to basal area class. Relatively open ponderosa pine points (25-125 ft^2 basal area) contained more than twice the number of infected trees, and associated basal area, than did other points. The densest points had more infected trees, proportionately, than the medium points.

Open points may have more dwarf mistletoe because of the lack of screening to hamper the spread of the disease. Hawksworth (1961) reported that ponderosa pine dwarf mistletoe progresses faster through an open stand than through a dense stand. The increase in dense stands may be related to the close proximity of host trees to each other. We did not study the position of trees around individual points. It is also possible that a multicanopy situation existed in the densest stands.

Relative Basal Area of Host Species. The next step was to evaluate the occurrence of dwarf mistletoe with respect to the relative basal area of the host species. The proportion of Douglas-fir trees infected with dwarf mistletoe was highest (32%) on areas where the species contributed between 26% and 50% of the point basal area. The proportion was smallest (8%) on points where 76% to 100% of the trees were Douglas-fir. The 51% to 75% class also contained more infection (16%) than did the 76% to 100% class.

The opposite was true in ponderosa pine. The 76% to 100% class contained the greatest amount of dwarf mistletoe — 51% compared to 21% for the other three classes. The incidence level was lowest in the 1% to 25% class (12%) where ponderosa pine was most isolated.

The differences in parasite occurrence between Douglas-fir and ponderosa pine is probably related to screening, or lack of it. The relatively high amount of infection in Douglas-fir in the 26% to 50% density class may be related to occurrence of clusters of host trees within the plots.

Combined Stand Characteristics Class. We also evaluated possible second-order interactions among stand characteristics by combining the data to create three combined classes for each species. Only physically significant combinations were analyzed (table 7).

The interaction analysis indicated that the greatest proportion of infected Douglas-fir trees (46%) was found where the species made up from 26% to 50% of the basal area distributed among three size classes. The percentage of basal area in infected trees was greatest (67%) on relatively open sites where the host made up 25% or less of the stand basal area. The smallest proportions of trees with *A. douglasii* (2%) were in dense stands with one size class. The amount of *A. vaginatum* was greatest in pure ponderosa pine stands with two size classes — 84% of the trees constituting 63% of the basal area.

Table 7.—Percentages of Douglas-fir and ponderosa pine infected with dwarf mistletoes by selected cells from six stand characteristic interaction tables (per-acre basis)

Stand characteristic interaction	Greatest occurrence			Most common site			Least occurrence		
	Stand characteristic	Trees	Basal area	Stand characteristics	Trees	Basal area	Stand characteristic	Trees	Basal area
				Douglas-fir					
Basal area classes x no. size classes	≥ 275 ft² x 3	41	47	150-250 ft² x 1	30	54	≥ 275 ft² x 1	2	26
	≥ 275 ft² x 2	6	58						
Percent host basal area x no. size classes	26-50% x 3	46	55	≤ 25% x 1	17	42	51-75% x 2	4	41
							26-50% x 4	28	28
Basal area class x percent host basal area	≥ 275 ft² x 26-50%	42	52	150-250 ft² x ≤ 25%	20	40	≥ 275 ft² x ≤ 25%	3	34
	25-125 ft² x ≤ 25%	33	67	150-250 ft² x 26-50%	26	56	150-250 ft² x 76-100%	4	22
				Ponderosa pine					
Basal area classes x no. size classes	≥ 275 ft² x 2	80	36	150-250 ft² x 1	14	26	≥ 275 ft² x 1	9	10
	25-125 ft² x 3	67	47						
Percent host basal area x no. size classes	76-100% x 2	84	63	≤ 25% x 1	14	22	≤ 25% x 2	0	0
							26-50% x 3	11	19
Basal area class x percent host basal area	25-125 ft² x 26-50%	81	29	150-250 ft² x ≤ 25%	11	21	150-250 ft² x 51-75%	3	7
	25-125 ft² x 76-100%	73	51				≥ 275 ft² ≤ 25%	7	10

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Common and Scientific Names of Trees Mentioned

Engelmann spruce	*Picea engelmannii* Parry
Blue spruce	*Picea pungens* Engelm.
Rocky Mountain Douglas-fir	*Pseudotsuga menziesii* var. *glauca* (Beissn.) Franco
White fir	*Abies concolor* (Gord. and Glend.) Lindl.
Corkbark fir	*Abies lasiocarpa* var. *arizonica* (Merriam) Lemm.
Ponderosa pine	*Pinus ponderosa* Laws.
Southwestern white pine	*Pinus strobiformis* Engelm.
Quaking aspen	*Populus tremuloides* Michx.

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Gottfried, Gerald J., and Robert S. Embry. 1977. Distribution of Douglas-fir and ponderosa pine dwarf mistletoes in a virgin Arizona mixed conifer stand. USDA For. Serv. Res. Pap. RM-192, 16 p. Rocky Mt. For. and Range Exp. Stn., Fort Collins, Colo. 80521.

Douglas-fir and ponderosa pine dwarf mistletoes are common in a 1,800-acre virgin mixed conifer stand in eastern Arizona. Dwarf mistletoes occur on approximately 21% of the Douglas-fir trees and 38% of the ponderosa pine trees. These make up 47% and 22% of the respective basal areas. The proportion and distribution of infected trees vary by topography and stand characteristics. Infestation will increase under the selection or shelterwood methods unless control measures are considered.

Keywords: *Arceuthobium, Arceuthobium douglasii, Arceuthobium vaginatum* subsp. *cryptopodum, Pseudotsuga menziesii, Pinus ponderosa,* mixed conifers.

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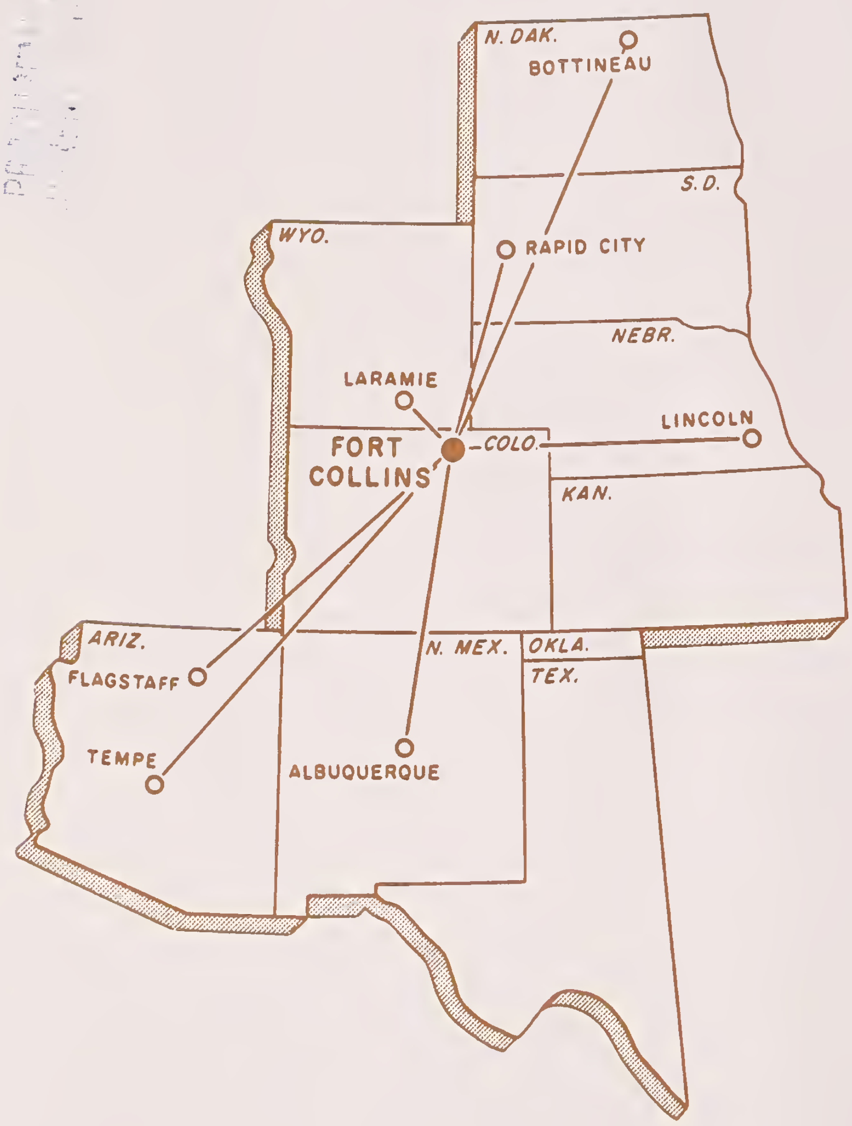
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